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Introduction of New Housing Method in Nepal Following the Vernacular Method Hybrid with 2×4 Technology Transfer from Japan

在来工法と日本型 2x4 技術の融合によるネパールにおける新たな住宅工法の導入可能性

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Summary of dissertation

Introduction:

Nepal occupying the central most part of the Himalayan region that lies on the northern part of Indian tectonic plate is seismically very active. Annually thousands of tremors of various intensities occur in this region. History shows that Nepal has hosted several large earthquakes in the cycle of hundreds years or less, and it is pity to say that the settlements in Nepal are still non-engineered and hardly few percentage of houses are earthquake resilient buildings. Recently in 2015 Gurkha earthquake of magnitude 7.8 has hit in the eastern part of Nepal. The severe impact of 2015 Gurkha earthquake is reflected in terms of 8790 causalities, 22300 injuries and 498852 houses completely or partially collapsed and other 256697 houses partly damaged (PDNA, 2015). On the other hand, Nepal consists of 83% rural population and about 90% of total houses in Nepal are non-engineered constructions which prove the huge existence of vernacular non-engineered residents (UN-Habitat 2013).

Thus the contemporary architecture and building technology of modern reinforced concrete houses as well as unreinforced masonry and adobe houses in Nepal are being criticized after the failure in each earthquake in the past and huge losses was noticed during natural calamities.

In a contrary, most of the timber framed Vernacular architecture which still stands after several earthquakes in the past has proven its resistance against the earthquake. Vernacular architecture is the result of hundreds of years of experiences and optimization to provide a comfortable shelter in their respective environmental situations.

Acknowledging the past earthquake destructions to modern concrete buildings and structures but less damage to vernacular architecture compelled me to think about the new ways of building with light material and new technology that could serve as earthquake resilient houses. In this study a newer way of constructing residential houses was proposed with traditional technique implemented in certain joint and joist in hybrid with modern 2×4 technology of Japan as an alternative solution for residential construction where the wood shear walls stand as lateral load resisting system. This study also analyzes how the new technology incorporates with lateral forces so that the buildings gain the best performance aesthetically and structurally. The load calculation was carried out on the new model house under the Japanese construction law of article 46 comparing the actual and necessary wall quantity (where Actual wall quantity $\boldsymbol{Ld} \geqq$ Necessary Wall quantity $\boldsymbol{Ln}$).

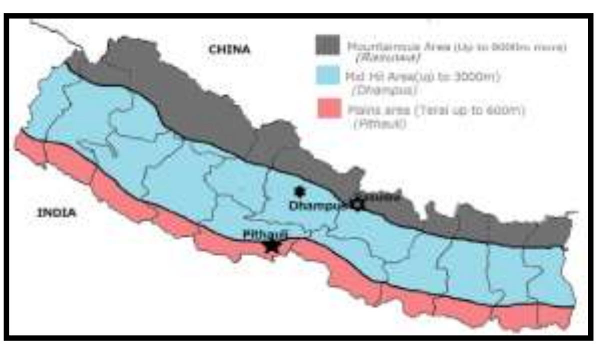

Figure 1a: Topographic map of Nepal (Edited by Author)
(Source: Map of Nepal)

Figure 1b: Topographic map of Nepal (Edited by Author)
(Source: Map of Nepal)

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Aims of this Study:

- To study in detail about the vernacular techniques of building residential houses of Nepal, their building materials that adapt to the extremities of climatic variations.

To introduce and establish the proposed model house as an experimental model house which is a HYBRID of

- Nepalese vernacular post and beam techniques with 2 by 4 technology of wooden frame method, for the first time in Nepal.

- Here HYBRID means blending of Nepali Vernacular post and beam technique with 2 by 4 technology of wooden frame housing of Japan to create an earthquake resilient house preserving Nepali culture enhanced with engineering and sophisticated features of resilient house for the first time in Nepal.

Methodology:

1) Survey was carried out by field visit and interviews with the victims of the 2015 Earthquake. Total of 120 unit local households were asked by questionnaires to understand the perspectives of 2015 Gurkha earthquake sufferers towards their concept of safe housing after the heavy causalities in haphazardly built non-engineered masonry and concrete structures of the urban areas.
2) Study in detail about the Vernacular houses in three different geographical regions of Nepal i.e.; Low land of terai, Mid-Hilly and High-Hilly regions, their building materials, building techniques, their adaptation to the extremities of climatic variations.
3) Taking into the features of Vernacular houses a Hybrid concept was developed which is a blend of Nepalese Vernacular techniques with 2 by 4 method of wooden frame housing of Japan. The model house with hybrid building technology was built with shear wall calculation, in lekhnath Pokhara of Nepal. For this the building materials like gypsum board, wooden plums, insulating materials, the bolt and nails for connections were all imported from Japan to Nepal.

House and Households

Table 1: % of households by type of houses for different ecological regions

Houses types	Mountain	Hill	Terai
Pakki	44.8	51.1	20.8
Ardha-Pakki	41.6	30.8	25.7
Kachhi	13	17.6	52.4
Others	0.6	0.5	1

Permanent materials like aggregate, sand, stone, concrete, mortar, mud wall with slate roof is defined as permanent house (Pakki) which are abundant in the Urban and city area with government Buildings.
Ardha Pakki means semi-permanent considered as strong with infill wall with stone, mud, brick with wood band. These types of houses have heavy causalities during earthquake.
Similarly, Kacchi refers to temporary shelters materials like wooden flakes, bamboo and mud finishing.

Among the three different regions of Nepal higher percentage of households are living with Pakki houses in hilly region followed by mountains and least numbers are in terai region. Whereas number of people living in kacchi houses in terai is higher followed by hill and least recorded in Mountain Region.

Study on Vernacular Settlements

Paul Oliver, 1997 “Vernacular architecture, given the insights it gives into issue of environmental adaptation, will be necessary in the future to ensure sustainability in both cultural and economic terms beyond the short term”. In simple words Oliver defined the vernacular architecture as: “the architecture of the people, and by the people, but not for the people”.

In this study the targeted area of vernacular housing study was in the Terai (plain land) region represented by Pithauli of Tharu ethnic group, Mid hilly region represented by Gurung ethnic groups and High Hilly region represented by Tamang ethnic group. Here various architectural expression differences can be found in respective regions.

Wooden Vernacular Architecture in Nepal

In most of the Vernacular structures, traditional timber frame buildings are built where structural and finish elements fit together using complex wooden joinery. On site, these components are tightly fit together using traditional equipment like hammer, saw and wood peg that last for centuries. In vernacular housing, post-beam method is used frequently in Nepal. Post and beam used as the only structural system that are connected by wood pegs that put onto the holes in mating frame elements and tied by wooden bands make stiff connection.

Figure 2 shows the Nepalese traditional post-beam method using traditional joinery like mortise and tenon, dovetails and tongue connections which is similar to Japanese traditional buildings where mechanical fasteners and steel plate connectors being used these days to join adjacent members together. Hence, the earthquake performance of wooden houses has generally been good, particularly that of wooden frame, and also where the cladding consists of sheathing, boarding, ikra walling, bamboo matting etc (Anand S Arya, Non-Engineered Construction in Developing Countries-An approach toward earthquake risk prediction 12WCEE 2000).

Having the advantage of post and beam structure in non-engineered vernacular structures of Nepal, the failure exists in the wall system where the walls are just the infill, not adjoining with each other and have no connection with wall frames thus leading to wide cracks in walls, separation of walls at corners and complete collapse of walls during past earthquakes. Besides this the poor performance of wooden structures exist in their biodegradation of woods and poor fire resistance as the technology for seasoning of wood has not yet been developed in Nepal.

In this study, learning from the traditional architecture, traditional specimens as structural system, a new building techniques can be developed by incorporating the Nepalese vernacular wooden structure with Japanese technology of 2 by 4 method where walls are fastened by steel connector and walls are infill by shear panel of 2-by-4 studs to create a stable structure.

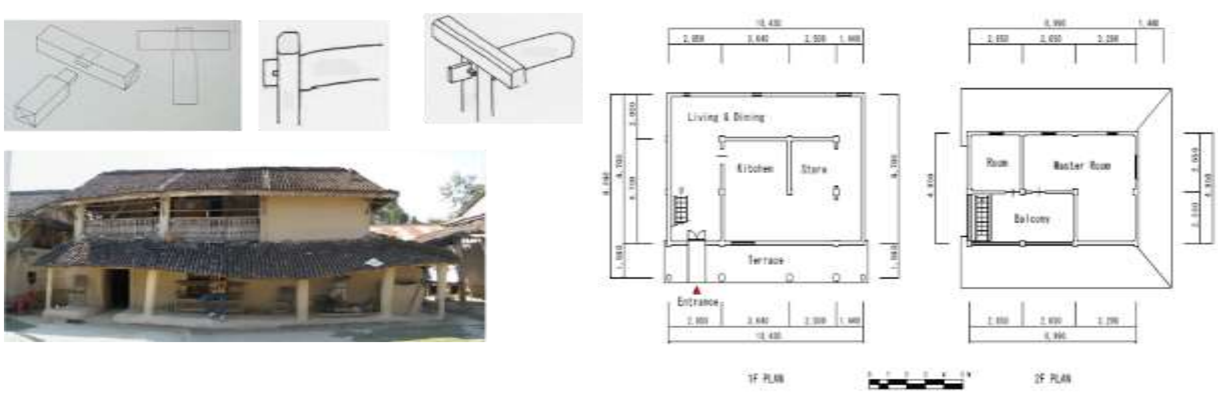

Figure 2: Traditional thatched house with traditional joints of Post-Beam Structure

Introduction of Hybrid house by incorporating 2 by 4 Wood Frame Technology with Nepalese Vernacular Techniques

In this study proposed HYBRID house is a “blending and fusing of Vernacular building techniques of Nepal with elements and techniques of wood frame structure, called as 2 by 4 dimensional wood frame construction method transferred from Japan” HYBRID technique in the field of building houses is developed and executed in Korea Forest Research Institute in Korea where shear performance of Hybrid post and Beam wall system infilled with structural Insulation panel (SIP) has been studied. Compared to the traditional wet type infill wall components, the hybrid wall system has benefits, such as, higher structural capacity, better thermal insulation performance, and shorter construction term due to dry type construction (Moon-Jae Park et al., 2010 and Hwang, W.J & Kim,N.H.

2002).
Japan is one of the earthquake prone countries, hence after adapting from North America and testing 2 by 4 wooden frame housing in Japan in several earthquakes like after kobe earthquake, this has gained popularity. This study deals with the shear walls and earthquake coefficient factor in different zone in order to propose the best solution to the present deficiency in the construction technology. Infill walls and non-structural elements are urged to replace by engineered shear wall with PSW approaches for the lateral loads and gravity loads by the buildings. The vernacular buildings show some light structures that could be able to withstand in seismic forces however are not still safe to live.

The construction code should be mandatory with easily applicable and professional direction should be need for safety living. While designing the buildings following the code according to international practices under NBC norms lateral loads generated due to earthquake, lateral loads may be transferred to the foundation via braced frames or rigid frames, diagonal rods or 'X' bracing. Where structural panels are used for roof, floors, or walls in a building lateral loads can be accommodated through the use of these ordinary vertical load-bearing elements. This type of construction is easily adaptable to conventional light frame construction typically used in residence. Application of HYBRID Housing is:
Introduction of 2 by 4 Panel of Shear walls into existing infill wall so as to gain the load bearing capacities, and to resist the lateral loads.
Calculation of weight of wall is done.
The wall and wall, wall and roof adjunct joints are connected with each other with following traditional technique of tenon and mortise strengthened by steel fasteners.
Thus by calculating the earthquake force and shear wall calculation it was proved to be earthquake resilient than existing houses of Nepal which are mostly non-engineered.

Results and Discussion:

Survey of Three Different geographical regions:

The field visit of three different regions of Nepal, the structural details, house patterns, and materials were analyzed and presented in Table 1 as outcomes from survey in respective region of study. The outcomes from traditional housing in different parts of Nepal are discussed as follows:

1) Vernacular Housings in three different geographical regions:

Table 2: Types of houses in three different geographical regions

Region	Building material	Type of Structures(Roof & Wall)	Sub type
Terai Region 70m to 600m Height	Abundant: wood, Mud, straw, bamboo, daub, other biogenic materials, sand, gravel	Adobe/Earthen unreinforced walls	1.Mud walls with straw and bamboo 2.Adobe block walls Rammed earth/PISE construction
		Load bearing timber frame	1.Thatch roof /Walls with bamboo Mesh 2. Post and beam frame(not tied)
Mid-Hilly Region Height varies from 700m to 2000m	Abundant: wood, Stone, block, other biogenic materials, mud, sand, gravel	Unreinforced masonry infill walls Wood post and beam structure.	1.Brick masonry in Mud/lime 2.Wood used for Post and Beam with weak join and juncture
		Roof Wood structure	Wood rafting/ shaft/Purlin. Timber roof
High- Hilly Region Height Upto3000m	Wood, stone, bamboo, mud	Wooden structure with reinforced walls	1. wooden wall, rammed earth 2. Corrugated metal roof, stone slate and no proper joint between roof and wall

2) Outcomes of the Survey: Failure in Modern Building Structures:

The most of the causalities in the past earthquake and the recent 2015 Gurkha earthquake was due to unreinforced masonry structures and non-engineered RC buildings constructed with brittle materials like adobe, brick and concrete blocks which resulted in the failing of ductility. Ductility is the ability to bend, sway and deform by large amount without collapse. These building constructions usually have not gone through the formal building permit processes and structural calculation considering seismic force and other parameters.

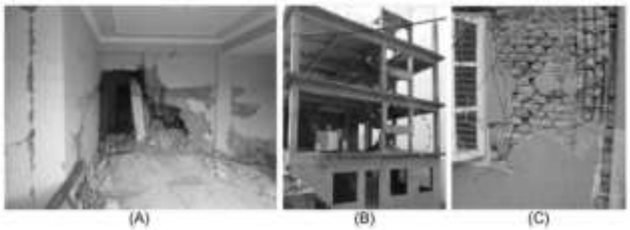

Figure 3a: Examples of short column failure (A): Staircase landing (B): Staircase landing beam (C) (figure imported from Varum, H et.al)

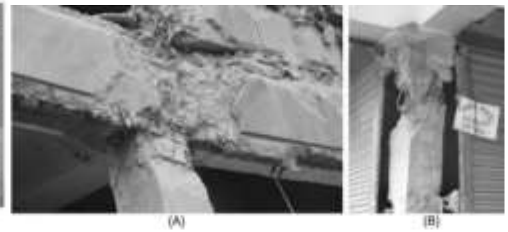

Figure 3b: Weak Beam-Column Joint Failure

The detail study revealing the following patterns of damages/failures in RC frame constructions in Kathmandu Valley (Figure 3a, 3b), after the Gurkha Earthquake 2015

- Shear failure and concrete crushing failure in concrete columns were extensively seen. These are the most undesirable non-ductile modes of failure. This behavior can lead to the loss of gravity load-bearing capacity in the columns and potentially a total collapse of walls and finally the building.
- Reduction in the amount of rebar reinforcement, and other building materials without engineering as per required.
- Due to the discontinuous load path, during the shake, the lateral forces are not effectively transferred to the foundation.

3) The Analysis of the Hybrid Model House: a) Safety and b) Cost Factor

Table 2: Calculation for earthquake and wind safety ratio

X Direction					Y Direction				
Required Wall Quantity for earthquake	Required Wall Quantity for Wind	Actual Wall Qty.	Earthquake safety Ratio	Wind safety Ratio	Required Wall Quantity for earthquake	Required Wall Quantity for Wind	Actual Wall Qty.	Earthquake safety Ratio	Wind safety Ratio
eLn[m]	wLn[m]	Ld[m]	Ld/eLn	Ld/wLn	eLn[m]	wLn[m]	Ld[m]	Ld/eLn	Ld/wLn
16.52	14.502	23.751	**1.43Ok**	**1.63 Ok**	16.52	11.095	29.029	**1.75Ok**	**2.61Ok**

a) Required wall quantity for earthquake [eLn] was calculated by

floor area [A] × *coefficient* [αE]: 0.15m/m^2×66.25m^2+0.15m/m^2×43.88m^2

Where floor area of 1F [A1] = 66.25m^2, floor area of 2F [A2] =43.88m^2, coefficient [αE] =0.15m/m^2 (following Building Standards Law of Japan)

***2 Required wall quantity for wind [wLn] was calculated by**

aspect area on each floor (2 directions) [A] × *wind coefficient* [αW]

Where the aspect area was calculated deducting the height of 1.35m from floor level of the model house by following Building Standards Law of Japan.

The 2 directions of the aspect area as east-west (X Direction) and north-south (Y Direction) direction was calculated to achieve wind force as shown in table 2 above.

The result shows that the Model hybrid wooden house is stronger for lateral forces by earthquake and wind forces. Hence this model house is sufficiently earth quake resilient building

b) Cost factor: Hence the safety factor, cost factor and efficiencies calculated are shown in table 3. The Cost of Wood Frame Hybrid model house is lower than engineered RC buildings and original 2 by 4 wood frame house which is even higher than RC constructions. The Hybrid model house having slightly lower safety factor than RC buildings with lower cost price, but having great variation in safety than traditional Vernacular buildings is most suitable alternative safer house for Nepalese people in the present scenario.

Table 3: The evaluation of HYBRID model house was done on the basis of Safety factor, Cost factor and Efficiency in comparison to same parameters of non-engineered and RC engineered houses

Comparing Parameters	Vernacular Houses (Non Engineered)	HYBRID Houses (New Concept House)	RC Structure (Engineered)	Pure 2 by 4 Houses
Safety Factor	F<1 *Characteristic Strength is difficult to clarify as using the multiple species of material and irregular spans	X-40.13 kN > ReqQi = 27.5 kN Y- 49.05 kN > ReqQl =27.5 kN	F>1.8 *Engineered/ fulfilling building Code	Japan Standard
Cost Factor NPR '000 (Model House)	2000	5200	6500	7920 *Assuming Nepalese labour cost
Efficiency	Null	Insulated with high efficiency * Visitors opinion at the site	Low efficiency of heating and cooling	High Efficiency (Japanese Standard)

Conclusion:

Many extensive researches have been performed on Japanese Post and Beam Technologies, for several decades. Many amendments, modification and revisions have been made and done in the decade-old building codes and standards. In the context of Nepal, new and revised Japanese building codes to build light houses which are resilient to earthquake as the light-frame walls provide resistance to sliding, overturning, and racking loads induced in the house by an earthquake, where highly sophisticated method and materials are integrated and introduced for the first time in the history of Nepal.

The outcome of the project was informative. Wooden house once forgotten can be re-introduced in Nepal.

Model house that was built prior to the 2015 Gorkha earthquake have shown their resistance strength against the great earthquake. The results of shear wall load calculation ($Ld \geq Ln$) suggest that the wooden model houses are sufficiently earthquake resistant. One of the main features of this method is introducing shear walls along with preserving joint and joist technique of traditional method.

This method also provides applicability to introduce shear walls in conventional masonry and RC buildings, which could avoid heavy losses from wall collapse due to the lateral loads caused by earthquakes. In addition, structures and materials used in this technology are light and environmentally friendly in contrary to contemporary RC residential buildings. Manufacturing/resizing of posts and 2 by 4 dimensional lumber can be done in Nepal so costs could be cut-down significantly. The frame of wooden wall can be introduced in the existing houses including vernacular houses in rural areas of Nepal to withstand the seismicity. Furthermore, the proposed new earthquake resistance housing technology is integrated with diaphragm of the buildings; hence, would have best performances aesthetically and structurally. Moreover, this technology is economic (table 2), simple and easily transferable to developing countries like Nepal.

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